International Soil and Water Conservation Research 4 (2016) 12–19

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Efficiency test of modeled empirical equations in predicting soil loss from ephemeral gully erosion around Mubi, Northeast Nigeria

Ijasini John Tekwa [a,*], Abubakar Musa Kundiri [b], Alhaji Maigana Chiroma [c]

[a] *Department of Agricultural Technology, The Federal Polytechnic, P.M.B 35, Mubi, Adamawa State, Nigeria*
[b] *Department of Soil Science, Faculty of Agriculture, Federal University Dutse, P.M.B 7156, Dutse, Jigawa State, Nigeria*
[c] *Department of Soil Science, Faculty of Agriculture, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State, Nigeria*

A R T I C L E I N F O

Article history:
Received 23 July 2015
Received in revised form
4 February 2016
Accepted 10 February 2016
Available online 20 February 2016

Keywords:
Empirical model
Soil loss
Prediction efficiency
Ephemeral gully erosion
Mubi
Northeast Nigeria

A B S T R A C T

A field study was carried out to assess soil loss from ephemeral gully (EG) erosion at 6 different locations (Digil, Vimtim, Muvur, Gella, Lamorde and Madanya) around the Mubi area between April, 2008 and October, 2009. Each location consisted of 3 watershed sites from where data was collected. EG shape, land use, and conservation practices were noted, while EG length, width, and depth were measured. Physico-chemical properties of the soils were studied in the field and laboratory. Soil loss was both measured and predicted using modeled empirical equations. Results showed that the soils are heterogeneous and lying on flat to hilly topographies with few grasses, shrubs and tree vegetations. The soils comprised of sand fractions that predominated the texture, with considerable silt and clay contents. The empirical soil loss was generally related with the measured soil loss and the predictions were widely reliable at all sites, regardless of season. The measured and empirical aggregate soil loss were more related in terms of volume of soil loss (VSL) (r^2=0.93) and mass of soil loss (MSL) (r^2=0.92), than area of soil loss (ASL) (r^2=0.27). The empirical estimates of VSL and MSL were consistently higher at Muvur (less vegetation) and lower at Madanya and Gella (denser vegetations) in both years. The maximum efficiency (M_{se}) of the empirical equation in predicting ASL was between 1.41 (Digil) and 89.07 (Lamorde), while the M_{se} was higher at Madanya (2.56) and lowest at Vimtim (15.66) in terms of VSL prediction efficiencies. The M_{se} also ranged from 1.84 (Madanya) to 15.74 (Vimtim) in respect of MSL predictions. These results led to the recommendation that soil conservationists, farmers, private and/or government agencies should implement the empirical model in erosion studies around Mubi area.

Contents

* Corresponding author.
E-mail address: jasini.john2@gmail.com (I.J. Tekwa).
Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

http://dx.doi.org/10.1016/j.iswcr.2016.02.002

1. Introduction

Studies on soil erosion have a long scientific history and are still ongoing with increasing focus on detailing erosion processes and their modeling. Development of suitable erosion models that can adequately predict the extent of soil loss have been a challenge to scientists since the 1930s (Lal, 2001). Though numerous erosion models have been developed using different methods and modeling approaches in the past, the concepts governing such erosion models differ widely and thereby, consistent modeling has not been established (Lal, 2001). For instance, the universal soil loss equation (USLE) (Wischmeier & Smith, 1978), its revised version (RUSLE) (Renard, Foster, Weesies, McCool & Yoder, 1997), and the modified universal soil loss equation (MUSLE) (Williams, 1982) were first used to estimate soil erosion and to select conservation and management practices for erosion control. However, these technologies did not estimate ephemeral gully (EG) erosion. Other models which were patterned after the USLE such as the soil loss estimation model for South Africa (SLEMSA) (Elwell, 1977; Elwell & Stocking, 1982), areal non-point source watershed environment response simulator (ANSWERS) (Beasley, Huggins & Monke, 1980), chemical, runoff, and erosion from agricultural management systems (CREAMS) (Knisel, 1980), and kinematic runoff and erosion model (KINEROS) (Woolhiser, Smith & Goodrich, 1990), among other empirical and physically-based models, were not capable of estimating soil erosion occurring in concentrated flow channels, where EG erosion occurs. EG erosion is a recently recognized class of water erosion (Foster, 1986), which causes irreversible and colossal losses of fertile agricultural land resources (Lal, 2001). It is a significant factor in soil erosion by water, whose visible damage is usually obliterated by farming operations. The magnitude of EG erosion is largely influenced by climate, topography and vegetation (Poesen, Nachtergaele, Verstraten & Valentine, 2003; Capra & Scicolone, 2002; Oygarden, 2003). Hence, selection of compatible conservation methods remains difficult, unless the type and magnitude of the erosion processes are correctly assessed.

Previous studies on ephemeral gully (EG) erosion under different climates and land use conditions reported between 10% and 100% of soil loss on agricultural lands in Europe (Poeson et. al., 2003), with annual soil loss ranging from 2 to 90 m^3 ha^{-1} in the Mediterranean areas (Capra & Scicolone, 2002). Qualitative estimates of the effects on soil productivity losses from water erosion were also reported for several regions of Africa (Dregne, 1990), Asia (Dregne 1992), Australia and New Zealand (Dregne, 1995) and North America (Den Biggelaar, Lal, Wiebe & Breneman, 2001). Despite the volumes of reports on EG erosion predictions around the World, there is still a dearth of information on this subject in the whole of the sub-Saharan Africa, and particularly Nigeria. At present, there are no formulated or tested indigenous erosion models for predicting soil loss from such EG or concentrated flow channels in this African sub-region. Hence, local adaptation of process-based models and erosion results from one region may not apply to another, due to differences in study methods, making data accuracy, reliability, and credibility debatable (Lal, 2001). Despite this limitation, there have been no EG studies in Nigeria, except for the studies of Tekwa and Usman (2006), Tekwa, Alhassand and Chiroma (2013) and Tekwa, Laflen and Yusuf (2014).

In light of these limitations, local efforts were first made to develop empirical erosion models (Tekwa et al. 2013, 2014), that are well simplified and representative of natural processes and field observations, and which would be useful and serve as suitable alternatives to the foreign-based sophisticated physically-based or conceptual models. Therefore, it was the lack of sufficient erosion models that necessitated the modeling of these empirical equations for possible implementation around the Mubi area. It is strongly hoped that the developed empirical models shall serve as a guide to conservationists, erosion specialists, field workers, and policy makers in their drive to curb erosion problems in the study area. Thus, the present work is aimed at testing the prediction efficiency of the locally developed empirical models and to provide plausible erosion control measures in the study area.

2. Materials and methods

2.1. Description of the study area

The selected sites are located in the Mubi North (Digil, Vimtim, and Muvur) and Mubi South (Gella, Lamorde and Madanya) local government areas of Adamawa state in northeast Nigeria (Fig. 1). The sites were selected based on their land use, topography, vegetation cover and soil type. Mubi South generally has higher topography, rockiness, and denser vegetations compared to Mubi North, which has more arable than grazing activities (Table C1). The climate of the Mubi area has two seasons, a wet and a dry season. The dry season spans from November to April, while the wet season runs from May to October. The annual rainfall in the area ranged between 700 mm and 1050 mm (Udo, 1970; Adebayo, 2004). The average minimum temperature is 15.2 °C in December and January, while the average maximum temperature of 42 °C occurs in the driest months of March or April (Adebayo & Tukur, 1999). The dominant vegetations are grasslands with scattered trees typical of a savannah region (Adebayo & Tukur; 1999; Adebayo, 2004; Tekwa & Usman, 2006). Land use types in the area are mixed farming: cattle rearing and arable farming that are confronted by erosion hazards each year. The hydrological data representation is adequate for the study sites, which are situated within 30–50 km as acceptable distances for hydrological data representation reported by the World Meteorological Organization in 2003.

2.2. Soil sampling and analysis

Representative composite soil samples were collected during the 2 growing seasons. A disturbed soil sample was collected from each of the 3 EG channels selected at each of the 6 sites. Soil samples (0–15 cm depth) were collected using a bucket auger, when the soils were relatively moist. Each composite soil sample was stored in a well labeled plastic bag. The samples were air-dried, crushed and sieved through a 2 mm sieve before laboratory determination of selected physical and chemical properties that have been found to be related to water erosion.

2.3. Determination of selected soil properties

The particle size distribution was determined using the Bouyocous hydrometer method (Trout, Garcia-castillas & Hart, 1987). The Atterberg limit (plasticity limit) was determined using a fall cone penetrometer method (Head, 1992). Bulk density was determined using the clod method (Wolf, 2003). The soil erodibility index (SEI) was

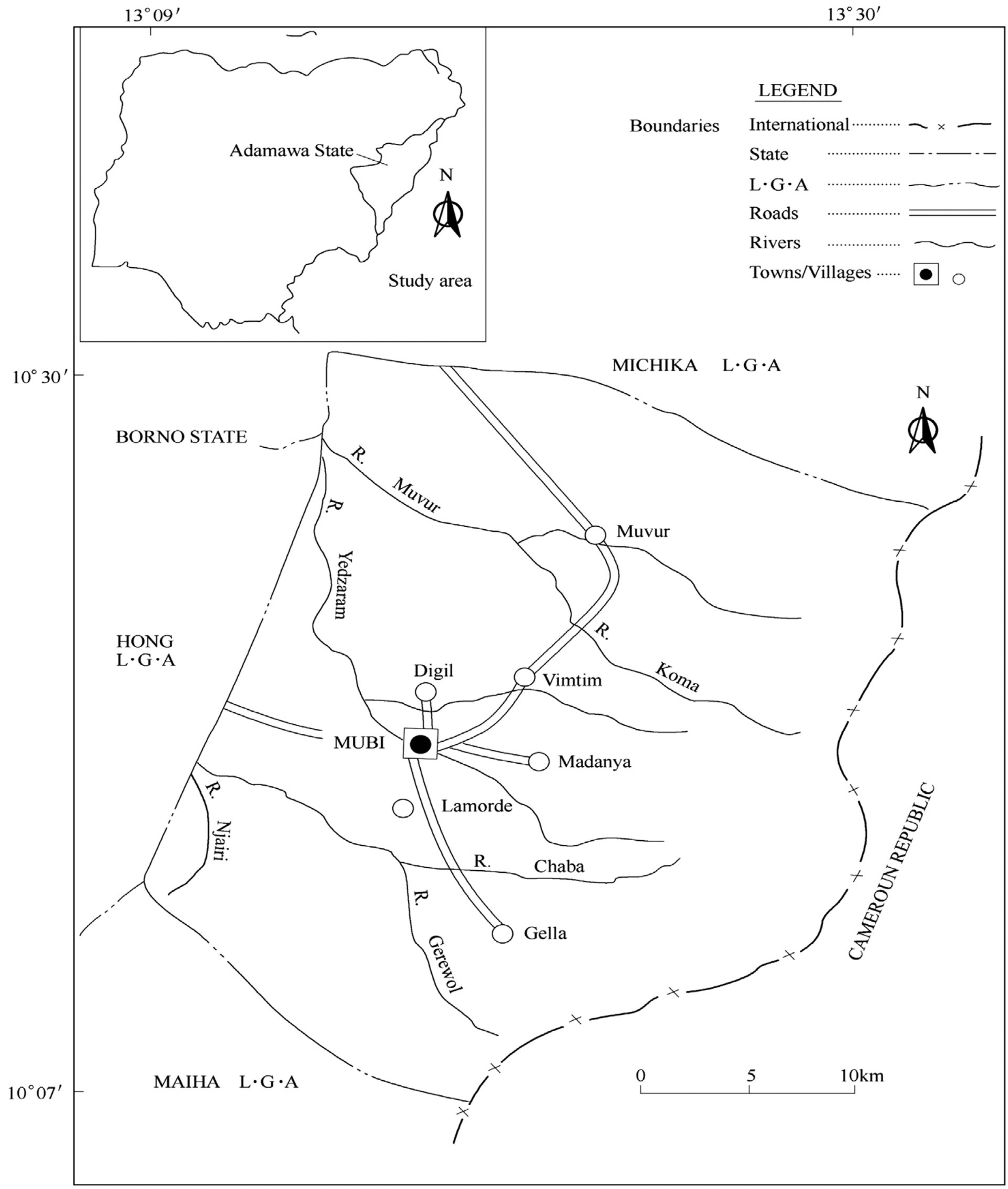

Fig. 1. Map of the study area showing farm sites, where EG features were observed. Adapted from Tekwa, Laflen, and Kundiri (2015).

computed in accordance with the 18 soil textural classes with corresponding SEI-values as described by Mitchell and Bubnezer (1993). The soil organic carbon (OC) content was determined using the potassium dichromate wet-oxidation method of Walkley and Black (1934). The O.C content was converted into organic matter (OM) content by multiplying with a factor of 1.724 (Wolf, 2003). The soil shear strength was computed in accordance with the expression described by Beasley et al., (1980) and as mentioned by Laflen, Watson, and Franti (1986), given as:

$$\tau c = 0.0065(10^{0.0182} \times \%\text{clay}) \quad (1)$$

where τc = critical shear strength.

2.4. Determination of EG channel properties

The EG channels approximate 'V' and 'U' shapes as defined by 'h' and 'W' in Fig. 2 (Watson, Laflen & Franti, 1986). Similar empirical methods used in different studies were successful, though results varied from place to place (Watson et al., 1986; Laflen et al., 1986; Tolu, 2002). The concentrated flow length (actual length of EG) and the EG maximum depth were determined using a measuring tape. The depleted width was determined in terms of the difference between the initial and maximum EG widths (Capra, Mazzara & Scicolone, 2004).

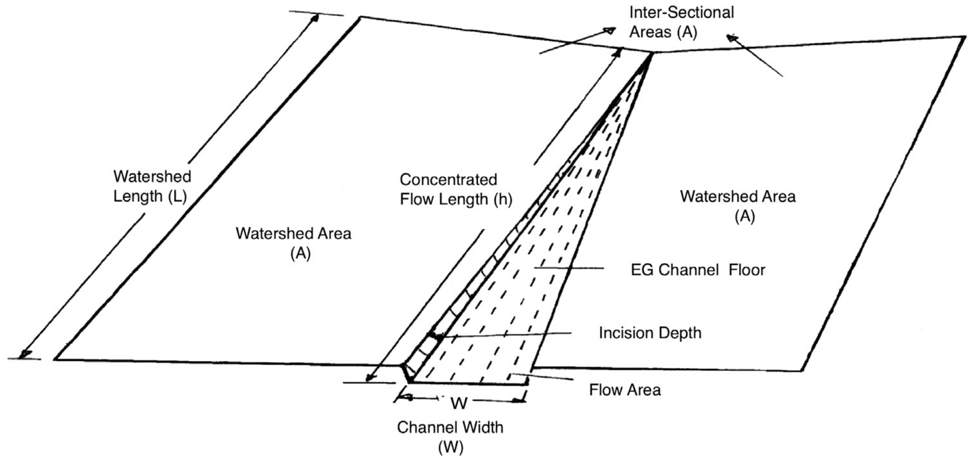

Fig. 2. A schematic diagram of an eroding EG channel in the field adapted from Watson et al. (1986).

Watershed slope rate was determined using an Abney level device as described by Tolu (1996). The volume of run-off water received on each EG site was auto generated by ephemeral gully erosion model (EGEM) (Laflen et al., 1986) from local rainfall data.

2.5. Measurement of soil loss in the study area

2.5.1. Area of soil loss (ASL)

The area of EG cylindrical shape that resembles a cylinder (Tolu, 2002), at before and after rainy seasons was computed and their differences represent the net area of soil loss for the season as determined as follows:

$$\text{Area of EG cylinder} = 2\pi rL \tag{2}$$

$$\text{Net area of EG cylinder} = 2\pi rL_2 - 2\pi rL_1 \tag{3}$$

where:

r=radius of a cylindrical EG shape.
L_1=length of EG channel before seasonal rainfall event.
L_2=length of EG channel after seasonal rainfall event.
π=constant of proportion.

The area of EG cone shape that resembles gully headcuts (Tolu, 2002), at before and after rainy seasons was also computed, and their margins represent the net average area of soil loss for the season, and determined as:

$$\text{Area of EG cone shaped} = \pi r(r + l) \tag{4}$$

$$\text{Net area of EG cone shaped} = \pi r(r + l)_2 - \pi r(r + l)_1 \tag{5}$$

where:

r=base radius of an EG cone shape,
l_1=slant height of EG cone shape before seasonal rainfall event,
l_2=slant height of EG cone shape after seasonal rainfall event,
π=constant of proportion.

The total ASL=Net area of EG cylinder shaped+Net area of EG cone shaped.

2.5.2. Volume of soil loss (VSL)

The volume of soil loss was similarly computed based on the cylinder and cone shapes of the EG erosion features as follows:

$$\text{Volume of soil loss (VSL) at EG head–cut (cone–shaped)} = \frac{1}{3}\pi r^2 h \tag{6}$$

$$\text{Net volume of soil loss (VSL2 –VSL1) at EG cone shaped} = \frac{1}{3}\pi r^2 h_2 - \frac{1}{3}\pi r^2 h_1 \tag{7}$$

where:

h_1=perpendicular height of gully head cone-shaped before seasonal rainfall event,
h_2=perpendicular height of gully head cone-shaped after seasonal rainfall event,
r=radius of an EG head-cut (Cone shaped),
π=Constant of proportion.

$$\text{Volume of soil loss along gully length (cylinder shaped) before rains} = \frac{1}{2}\pi r^2 L \tag{8}$$

$$\text{Net volume of soil loss along EG cylinder shaped} = \frac{1}{2}\pi r^2 L_2 - \frac{1}{2}\pi r^2 L_1 \tag{9}$$

where:

π=constant of proportion,
r=radius of gully basin (cylinder-shaped),
L_1=length of gully basin before seasonal rainfall event,
L_2=length of gully basin after seasonal rainfall event,
h=EG incision depth (cylinder shaped).

$$\text{Total VSL} = \text{Net VSL (EG cone shaped)} + \text{Net VSL (EG cylinder shaped)} \tag{10}$$

2.5.3. Mass of soil loss (MSL)

The mass of soil loss was calculated using the expression described by Wolf (2003):

$$\text{Mass of soil loss} = \text{Total volume of soil loss (VSL)} \times \text{Soil } \delta_b \tag{11}$$

where δ_b=soil bulk density.

2.6. Determination of empirical soil loss in the study area

Empirical models are products of few different interacting erosion variables, whose individual effects are determined from multiple regression coefficients (Wischmeier & Smith, 1978; Watson et al., 1986; Tolu, 2002, etc.), and are most importantly, usually simple, easy to develop and implement, than the scarce and rarely compatible sophisticated foreign erosion models (Eisazadeh, Sokouti, Homaee & Pazira, 2012). These reasons formed the basis for the linear empirical equations modeled from quantitative field data using a multiple regression analysis earlier reported by Tekwa et al. (2013), as presented in (Eqs. (12)–14) below.

$$Y_{ASL} = 3166.40 - 2087.82(\delta_b) - 7.20977\,(\text{clay}) + 419.453\,(\text{SEI}) + 13.2948\,(\text{PL})\text{–}133.601(\text{OM}) - 7109.39(\text{TC}) + 2.90245\,(\text{SR}) + 480.420\,(\text{Run} - \text{off});\ \ r^2 = 0.40 \tag{12}$$

$$Y_{VSL} = 2170.98 - 1556.63(\delta_b) - 4.8032\,(\text{clay}) + 868.765\,(\text{SEI}) + 13.0510\,(\text{PL})\text{–}102.693\,(\text{OM}) - 5322.86\,(\text{TC}) + 4.75836\,(\text{SR}) + 199.491\,(\text{Run} - \text{off});\ \ r^2 = 0.95 \tag{13}$$

$$Y_{MSL} = 2666.99 - 1899.59\,(\delta_b) - 6.93032\,(\text{clay}) + 1124.52\,(\text{SEI}) + 17.2004\,(\text{PL})\text{–}136.544\,(\text{OM}) - 7011.92\,(\text{TC}) + 6.60113\,(\text{SR}) + 284.778\,(\text{Run} - \text{off});\ \ r^2 = 0.94 \tag{14}$$

where:

Y_{ASL} = predicted area of soil loss,
Y_{VSL} = predicted volume of soil loss,
Y_{MSL} = predicted mass of soil loss,
δ_b = bulk density,
Clay = clay content,
SEI = erodibility index,
PL = plasticity index,
OM = organic matter content,
τc = shear strength,
SR = site slope rate,
Run-off = volume of run-off water,
r^2 = coefficient of determination.

2.7. Validation of empirical soil loss estimates

The empirically predicted estimates of soil loss (ASL, VSL, and MSL) were validated using a regression (regression graph) between empirical and measured soil loss. The level of association (r^2-value) between the measured and empirical estimates defined the percentage ability (reliability) of the empirical model for predicting soil erosion in the study area.

2.8. Data analysis

The data collected was analyzed using the generalized linear model in a randomized complete block design for the ANOVA (Statistix 9.0, 2012). The standard polynomial curves (2nd order) were also used to validate the relationships between the measured and empirical erosion. In addition, analysis of errors in predicting the empirical soil loss was determined using the standardized mean error (M_{es}) and root mean square error (M_{se}) as described by Capra et al., (2004), and expressed as:

$$M_{es} = \frac{1}{n}\Sigma((Z_i - Z_i^*)/S)^2 \tag{15}$$

$$M_{se} = [\frac{1}{n}\Sigma(Z_i - Z_i^*)^2]^{0.5} \tag{16}$$

where:

S = standard deviation of the measured soil loss,
n = number of observations,
Z_i = empirical soil loss estimate, and
$Z_i{}^*$ = measured soil loss estimate.

The M_{es} value is theoretically consistent, if the $M_{es} \equiv 1$, while the best M_{se} is achieved with as low value as possible (Capra et al., 2004).

Table 1
Efficiency test of the empirical equations in predicting aggregate soil loss estimates in the study sites.

Study location Mubi North	Mubi South	**Soil loss** **Measured**	**Empirical**	**Error analysis** R^2	M_{es}	M_{se}
		Area of soil loss prediction accuracy (m^2)				
Digil		240	294	0.29	0.07	1.41
Vimtim		316	325	0.31	0.00	5.32
Muvur		470	394	1.00	7.49	43.95
	Gella	401	280	0.98	0.07	70.11
	Lamorde	119	273	0.94	2.66	89.07
	Madanya	175	170	0.67	0.05	3.01
		Volume of soil loss prediction accuracy (m^3)				
Digil		173	196	0.33	0.09	13.52
Vimtim		303	276	0.99	0.01	15.66
Muvur		305	320	0.89	0.01	8.19
	Gella	133	125	0.99	0.00	4.63
	Lamorde	162	170	0.98	0.01	4.68
	Madanya	82	86	0.98	0.01	2.56
		Mass of soil loss prediction accuracy (kg/ha)				
Digil		24	266	0.38	0.04	13.25
Vimtim		395	368	0.97	0.00	15.74
Muvur		399	415	0.87	0.01	9.46
	Gella	177	165	0.99	0.01	7.12
	Lamorde	212	224	0.99	0.02	6.81
	Madanya	107	110	0.98	0.00	1.84

Key: R^2 = coefficient of determination, M_{es} = standard mean error, M_{se} = root mean square error.

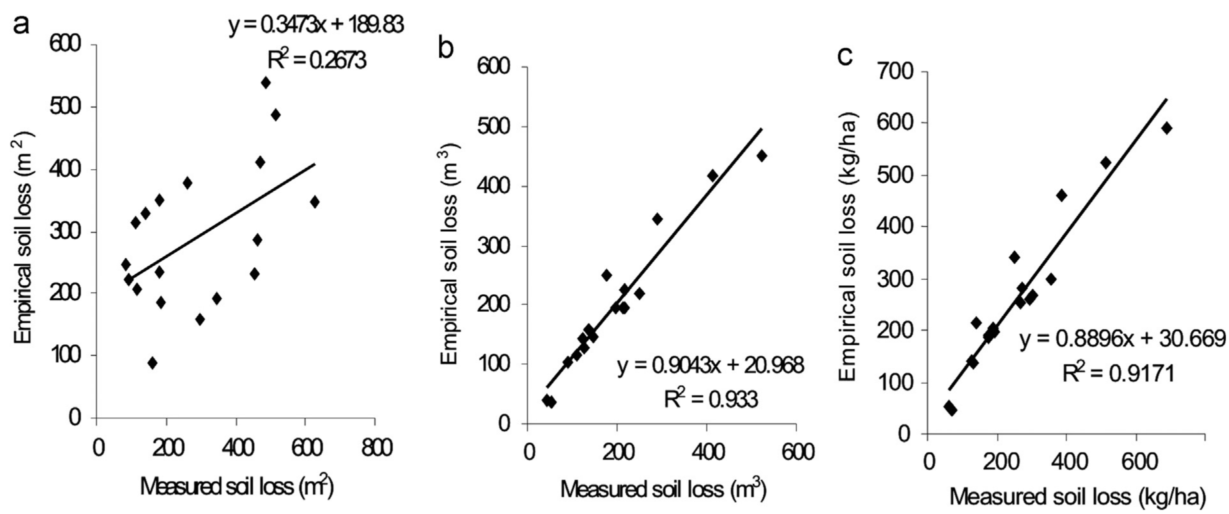

Fig. 3. Relationships between measured and empirical aggregate estimates of: (a) ASL, (b) VSL and (c) MSL across the 6 sites.

3. Results and discussion

3.1. Erosion site characteristics

Characteristics of the erosion sites are heterogeneous in nature with EG channels having "V" and "U" shapes due to seasonal channel incisions by run-off water on mostly rolling terrains (Tekwa et al., 2013). There are fewer grasses and trees at Mubi North (e.g. Vimtim and Digil), than at Mubi South (e.g. Gella and Lamorde), which also influenced agricultural tillage activities. Some conservation practices such as vegetative barriers, terraces, and tied-ridges and rough tillage are used as erosion controls around Mubi area (Ekwue and Tashiwa, 1992; Tekwa et al., 2014). The soils are generally sandy clay loamed, except Gella with sandy loam texture (Tekwa et al., 2014). The soil organic matter was low and inadequate to have reduced erosion losses in the study area.

3.2. Relationship between measured and empirical soil loss estimates

Results in respect of the empirical ASL, VSL, and MSL in the various study sites expressed a low to high relationships (Table 1). The measured and empirical ASL estimates had R^2 values up to 100%, 98.3%, 94.4%, and 66.5% at Muvur, Gella, Lamorde and Madanya, with lower values indicating poor predictions of ASL at Vimtim and Digil. The high relationship observed between measured and empirical ASL at Muvur was perhaps due to efficiency of the erosion variables in determining actual erosion at the sites. A similar R^2 of 91% was also observed between measured and empirical soil loss parameters in the Mediterranean environment (Nachtergaele et al., 2001b).

The measured and empirical VSL R^2 were 99.7%, 99.1%, 97.9%, 97.6% and 98.2% at Gella, Vimtim, Lamorde, Madanya and Muvur, compared to their poor relationship at Digil (33.1%). The relationship between empirical and measured VSL was generally high. In other words, the empirical equation sufficiently predicted the extent of VSL in the various sites, except at Digil. These good predictions agree with the report of Laflen, Flanagan, and Engel (2004), that good vegetation cover condition is an essential variable that reduces soil erosion on most watersheds. Similar work by Capra et al. (2004), however, found a good relationship ($r^2=0.64$) between EG length and volume, when studying EG erosion.

On the other hand, the R^2 values of 99.5%, 98.7%, 98.4%, 97.1%, 87.0% and 38.3%, respectively at Lamorde, Gella, Madanya, Vimtim, Muvur and Digil indicated high associations between measured and empirical erosion. The results suggest that the empirical equation was well related with measured MSL estimates at all sites, except at Digil, as it was in the case of VSL prediction. This outcome was perhaps due to the spurious correlation between measured and empirical variables. The widely observed high rates of prediction efficiency appear higher than those reported (91%) by Nachtergaele et al., (2001b), which further explains the relevance of the erosion predictors in this work.

On the aggregate, the results showed that the R^2 between measured and empirical ASL, VSL, and MSL were 26.7%, 93.3%, and 91.7% across the sites, as shown in Fig. 3. There was very low to high relationships between the aggregate estimates of measured and empirical EG erosion types (ASL, VSL and MSL) in this study. The empirical model could not adequately predict the extent of ASL ($r^2=0.27$) in this study. However, the empirical equation was able to predict both VSL ($r^2=0.93$) and MSL ($r^2=0.92$) with higher precisions. The relative efficiency of empirical over physically based models (e.g. EGEM) has since been reported by Nachtergaele Poeson, Vandekerckove, Oostwoud and Roxoet (2001a) and Nachtergaele et al. (2001b) and Capra et al. (2004).

3.3. Efficiency of the modeled empirical erosion in the study sites

The results showed that the empirical ASL prediction was reliable at Vimtim, Madanya, Gella, and Digil with a standardized mean error (M_{es}) of 0.00, 0.05, 0.07, and 0.07 respectively, while it was comparably less efficient at Muvur and Lamorde with a respective M_{es} of 7.49 and 2.66. Conversely, the maximum efficiency (M_{se}) of the empirical equation in the sites was in the order: Digil (1.41) ≥ Madanya (3.01) ≥ Vimtim (5.32) > Muvur (43.95) > Gella (70.11) ≥ Lamorde (89.07). The empirical equation prediction was observed as efficient at Vimtim, Madanya, Digil, and Gella, compared to Lamorde and Muvur. Even though, there was a high association between predicted and measured as observed at most of the sites. Also, the corresponding M_{se} fairly correlated with the observed M_{es}, depicting the models' accuracy as adequate in some of the sites.

The high association was likely due to the empirical nature of the modeled equation in relation to the measured ASL. This agrees with the report of Capra et al. (2004), that performance of empirical models was no worse than the better tested EGEM output in the Mediterranean environments. The observed results of this study have underscored the reasons for the formulation and trial of these simple empirical models in the host environment, as such shall not only guide potential users on erosion problems, but as well may serve as a foundation for future development of physically-based and/or conceptual models in the study area.

The results also showed that the empirical VSL prediction was generally efficient at all of the sites. The M_{es} in the sites was in the order: Gella (0.00) ≥ Madanya (0.01) = Vimtim (0.01) = Muvur (0.01) = Lamorde (0.01) ≥ Digil (0.09). In addition, the M_{se} of the empirical equation corresponded well with the observed M_{es} values. The M_{se} was best at Madanya (2.56) compared to Vimtim (15.66), being the least reliable among the sites. The empirical equation was however, observed to be fairer in its prediction efficiency in this study.

Nachtergaele et al. (2001a) and Capra et al. (2004) similarly observed that empirical studies gave more accurate estimates of eroded volume, when compared with those of EGEM at the Mediterranean Loess belt. This suggests that the tested empirical models may not only be easy alternatives to use, but shall also favorably compare with even the sophisticated physically-based or conceptual models in the area. In addition, the M_{es} and M_{se} indices due to these models were also observed to be fairer than the range of 0.7–4.5 and 14.8–96.4 for eroded volumes earlier reported by Capra et al. (2004) from a similar work in Sicily, Italy.

The results further revealed that the empirical MSL prediction was generally efficient at all sites, as it was in the case of VSL predictions. On the other hand, the M_{se} of the empirical equation in the sites was in the order: Madanya (1.84) > Lamorde (6.81) ≥ Gella (7.12) ≥ Muvur (9.46) > Digil (13.25) > Vimtim (15.74). The result of empirical prediction was also widely efficient in predicting MSL across the sites, as it was the case for VSL predictions. Both the M_{es} and M_{se} indices observed in this work appear fairer than those earlier reported by Capra et al. (2004). This trend is still likely due to the individual prediction ability of the empirical equation as earlier emphasized by Nachtergaele et al. (2001a), Capra et al. (2004), and Nasri, Feiznia, Jafari, and Ahmadi (2008).

4. Conclusion

The empirical model prediction efficiency was largely found to be reliable at all of the sites, regardless of season. However, the accuracy of the empirical model was better in terms of VSL (r^2=0.93) and MSL (r^2=0.92), than for ASL (r^2=0.27) predictions on an aggregate basis. The empirical estimates of VSL and MSL were consistently higher at Muvur (scanty vegetation) and lower at Madanya and Gella (denser vegetations) in both years. It suffices to conclude that the modeled empirical equations could serve as suitable alternatives to the rigorous field measurement methods of EG erosion studies in Mubi area of northeastern Nigeria.

5. Recommendations

The modeled equations are strongly recommended for implementation among farmers, soil conservationists, environmental protectionists, and other private and/or governmental agencies in their policy issues regarding erosion studies in the Mubi area. Incorporation of erosion variables such as channel parameters (length, width, and depth), TEB content as additional input variables in the empirical model is recommended for possible improvement of especially ASL prediction efficiency in the study area.

Appendix A

See (Table A1).

Appendix B

See (Table B1).

Table A1
Aggregate values of selected soil erosion predictor variables.

Site location	Erosion predictor variables							
	Bulk density (δ_b) (Mg/m^3)	Clay content (%)	Organic matter content	SEI	Soil shear stress (τc) (N/m^2)	Plasticity limit	Slope rate (%)	Run-off volume (cfs)
Mubi North								
Digil	1.42	26.25	0.77	0.25	0.02	17.33	05.00	0.32
Vimtim	1.38	24.20	1.02	0.27	0.02	17.67	15.00	0.23
Muvur	1.33	25.82	1.13	0.25	0.01	16.67	13.33	0.18
Mubi South								
Gella	1.32	19.33	0.90	0.17	0.01	0.00	15.00	0.24
Lamorde	1.34	24.38	1.32	0.22	0.02	5.67	21.67	0.22
Madanya	1.33	24.95	1.19	0.28	0.04	6.00	10.00	0.39

Key: SEI = soil erodibility index.

Table B1
Characteristics of EG channel parameters in the study area.

Site location Mubi North	Mubi South	Length (m) 2008	2009	Width (m) 2008	2009	Depth (cm) 2008	2009
Mean values of initial EG channel parameters							
Digil		98.33	103.17	2.42	2.80	26.67	30.48
Vimtim		125.16	132.82	2.42	3.25	25.96	34.29
Muvur		166.89	173.94	2.54	2.95	32.59	36.83
	Gella	85.32	93.16	1.23	2.32	20.32	24.13
	Lamorde	71.68	78.69	2.07	2.51	25.83	30.91
	Madanya	109.84	112.84	2.03	2.61	29.21	32.18
Net values of EG channel increase during the study period							
Digil		4.73	4.96	0.57	0.65	4.24	3.38
Vimtim		6.31	8.84	1.09	0.57	2.72	5.08
Muvur		8.01	12.19	1.01	0.51	4.24	4.24
	Gella	8.63	7.05	1.13	1.17	5.08	0.84
	Lamorde	4.35	4.03	0.66	0.30	5.92	4.24
	Madanya	7.02	9.85	0.78	0.37	5.92	3.38

Appendix C

See (Table C1).

Table C1
EG field conservation and vegetation cover characteristics.

Site location	EG channel shape	Field slope (%)	Soil texture	Land-use type	Soil surface cover condition	Conservation practice
Mubi North						
Digil	V	5	SCL	Arable/ grazing	Cultivated land, few grasses, shrubs, trees	Vegetative barrier, tied-ridging
Vimtim	U	15	SCL	Arable	Cultivated land with few grasses and trees	Rough tillage, tied ridging
Muvur	U	13	SCL	Arable/ grazing	Cultivated land with few grasses and trees	tied-ridging
Mubi South						
Gella	V	15	SL	Arable/ grazing	Cultivated land, trees, grasses and shrubs	Terraces, sand-bags/stone lines
Lamorde	U	21	SCL	Arable/ grazing	Cultivated land, trees and shrubs/grasses	Terraces, sand-bags/stone lines
Madanya	U	10	SCL	Arable/grazing	Cultivated land, few grasses and shrubs	Vegetative barrier, tied ridging

References

Adebayo, A. A. (2004). *Mubi region: a geographical synthesis* (1st ed.). Yola-Nigeria: Paraclete Publishers.
Adebayo, A. A., & Tukur, A. L. (1999). *Adamawa state in maps* (1st ed.). Yola: Department of Geography F.U.T.
Beasley, D. B., Huggins, L. F., & Monke, E. J. (1980). ANSWERS: a model for watershed planning. *Transactions of American Society of Agricultural Engineers*, *23*, 938–944.
Capra, A., Mazzara, L. M., & Scicolone, B. (2004). Application of the ephemeral gully erosion model to predict ephemeral gully erosion in Sicily. *Catena*, *59*, 1–13.
Capra, A., & Scicolone, B. (2002). Ephemeral gully erosion in a wheat cultivated area in Sicily (Italy). *Biosystems Engineering*, *83*.
Den Biggelaar, C., Lal, R., Wiebe, K., & Breneman, V. (2001). Impact of soil erosion on crop yields in North America. *Advances in Agronomy*, *45*, 431–437.
Dregne, H. E. (1990). Erosion and soil productivity in Africa. *Journal of Soil Water Conservation*, *45*, 431–437.
Dregne, H. E. (1992). Erosion and soil productivity in Asia. *Journal of Soil Water Conservation*, *47*, 8–13.
Dregne, H. E. (1995). Erosion and soil productivity in Australia and New Zealand. *Land Degradation and Rehabilitation*, *6*, 71–78.
Eisazadeh, L., Sokouti, R., Homaee, M., & Pazira, E. (2012). Comparison of empirical models to estimate soil erosion and sediment yield in micro catchments. *Eurasian Journal of Soil Science* (pp. 28–33), 28–33 ⟨http://fesss.org/eurasian_journal_of_soil_science.asp⟩.
Ekwue, E. I., & Tashiwa, Y. I. (1992). Survey of Gully Erosion Features in Mubi Local Government Area of Adamawa State. *Annals of Borno*, *8/9*, 181–191.
Elwell H.A. (1977). Soil loss estimation for southern Africa. Research Bulletin 22. Department of Conservation and Extension: Harare, Zimbabwe.
Elwell, H. A., & Stocking, M. A. (1982). Developing a simple yet practical method of soil loss estimation. *Tropical Agriculture*, *59*, 43–48.
Foster, G. R. (1986). *Understanding ephemeral gully erosion. Soil conservation, assessing the national research inventory* (pp. 90–118)Washington, DC: National Academy Press.
Head, K. H. (1992). *Manual of Soil Laboratory Testing. Soil classification and Compaction Tests*. 1. London: Pentech Press.
Knisel, W.G. (1980). CREAMS: a filed-scale model for chemicals, run-off, and erosion from agricultural management systems, Conservation research report No. 26. U. S. Dept. of Agric.
Laflen, J. M., Flanagan, D. C., & Engel, B. (2004). Soil erosion and sediment yield prediction accuracy using WEPP. *Journal of the American Water Resources Association (JAWRA)*(47907–1146), 289–297.
Laflen, J.M., Watson D.A., Franti T.G. (1986). Ephemeral gully erosion. In: Proceeding of 4th Federal Agency Sedimentation Conference Vol. 1 (pp. 3–37). Interagency Advisory Committee on Water Data, Subcommittee on Sedimentation.
Lal, R. (2001). *Soil degradation by erosion*. 12. USA: John Wiley & Sons Ltd.
Mitchell, J. S. K., & Bubnezer, G. D. (1993). *Fundamentals of soil behavior* (2nd ed.). New York: John Wiley.
Nachtergaele, J. J., Poeson, J., Vandekerckove, D., Oostwoud, W., & Roxo, M. (2001a). Testing the ephemeral gully erosion model (EGEM) for two Mediterranean environments. *Earth Surface Processes and Land Forms*, *26*, 17–30.
Nachtergaele, J. J., Poeson, J. A., Steegen, I., Takken, L., Beuselinck, L., Vandekereckove, G., & Grovers, G. (2001b). The value of a physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loss-dierived soils. *Geomorphology*, *40*, 237–252.
Nasri, M., Feiznia, S., Jafari, M., & Ahmadi, H. (2008). Using field indices of rill and gully in order for erosion estimating and sediment analysis (Case study: Menderjan Watershed in Isfahan Province, Iran). *World Academy of Science, Engineering and Technology*, *43*, 370–376.
Oygarden, L. (2003). Rill and gully development during an extreme winter runoff event in Norway. *Catena*, *50*, 217–242.
Poesen, J., Nachtergaele, J. J., Verstraten, G., & Valentine, C. (2003). Gully erosion and environmental change: importance and research needs. *Catena*, *50*(2–4), 91–133.
Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. (1997). Predicting soil erosion by water – a guide to conservation planning with the revised universal soil loss equation (RUSLE), Agr. Handbook No. 703. U.S. Dept. of Agric.
Statistix 9.0 (2012). Statistical package for scientists and engineers. Analytical softwares- StatistiXL, USA.
Tekwa, I. J., & Usman, B. H. (2006). Estimation of Soil loss by gully erosion in Mubi, Adamawa State, Nigeria. *Journal of the Environment*, *1*(1), 35–43.
Tekwa, I. J., Alhassan, A. B., & Chiroma, A. M. (2013). Effect of selected erosion predictors on seasonal soil loss from ephemeral gully erosion features in Mubi area, Northeastern Nigeria. *Scholarly Journal of Agricultural Science*, *3*(10), 401–409 Available online at:⟨http://www.scholarly-journals.com/SJAS⟩.
Tekwa, I. J., Laflen, J. M., & Kundiri, A. M. (2015). Efficiency test of adapted EGEM model in predicting ephemeral gully erosion around Mubi, Northeast, Nigeria. *International Soil and Water Conservation Journal*, *3*(1), 15–27 Available online at: ⟨www.sciencedirect.com; www.elsevier.com/locate/iswcr⟩.
Tekwa, I. J., Laflen, J. M., & Yusuf, Z. (2014). Estimation of monthly soil loss from ephemeral gully erosion features in Mubi, Semi-arid Northeastern Nigeria. *International Research*, *4*(3), 51–58 Available online at:⟨http://www.resjournals.com/ARJ⟩.
Tolu, T. (1996). Gully erosion control plan and measurement research report to Ethiopian. *Science and Technology Commission* (p. 162), 162.
Tolu, T. (2002). *Soil and Water Conservation for Sustainable Agriculture*. Kenya: Mega Publishing Enterprise.
Trout, T.T., Garcia-castillas, I.G., Hart, W.E. (1987). Soil water engineering field and laboratory manual. M/S Eurasia. New Delhi, India.
Udo, R. K. (1970). *Geographical reports of Nigeria* (1st ed.). London: Heinemann.
Walkley, A., & Black, C. (1934). Chronic acid titration method for determining soil organic matter. *Soil Science Society of America Journal*, *37*, 29.
Watson, D. J., Laflen, J. M., & Franti, T. G. (1986). Ephemeral gully erosion estimator, cited In: D. E. Woodward (Ed.), *Method to predict cropland ephemeral gully erosion*, 37 (pp. 393–399). Catena.
Williams, J.R. (1982). Sediment yield prediction with universal equation using runoff energy factor. In: Proceedings of workshop on estimating erosion and sediment yield on range lands (pp. 244–252). ARM-W-26, USDA-ARS: Washington, DC.
Wischmeier, W.H., Smith, D.D. (1978). Predicting rainfall erosion losses. USDA agriculture handbook. p. 537.
Wolf, B. (2003). *Diagnostic techniques for improving crop production*. USA: Haworth Press.
Woolhiser, D. A., Smith, R. E., & Goodrich, D. C. (1990). *KINERUS: a kinetic runoff and erosion model: documentation and user manual*. Washington, DC: ARS-77, USDA-ARS.